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Energetic Particle Observations at Geosynchronous Orbit

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1. INTRODUCTION

The region of space near geosynchronous altitudes is important for the processes which contribute to magnetic storms. During substorms magnetic energy is converted to particle kinetic energy resulting in the "substorm injections" commonly observed at geosynchronous orbit. These injections are manifested in energies from a few tens of keV to hundreds of keV and, on occasion, to the MeV energy range. The injected particles are subject to gradient and curvature drifts and therefore contribute to the ring current. It is common to think of a magnetic storm as a superposition of substorms in which the injection rate into the ring current exceeds the loss rate due to scattering, diffusion, and precipitation. In this paper we review current understanding of substorm injections and examine geosynchronous energetic particle data for the signatures of magnetic storms and for clues to the storm-substorm connection.

2. THE LOS ALAMOS ENERGETIC PARTICLE DATA SET

Los Alamos National Laboratory began flying energetic particle detectors at geosynchronous orbit in 1976. In 1977 a second spacecraft was launched and since 1979 three spacecraft have provided continuous and simultaneous monitoring of the geosynchronous energetic particle environment. This first generation of spacecraft carried the Charged Particle Analyzer (CPA) [*Higbie et al.*, 1978]. The CPA measures electrons from 30 keV to 2 MeV in 12 energy channels. It also measures protons with energies from approximately 70 keV to over 200 MeV in 26 energy channels. Five telescopes are mounted at various angles to the spin vector which points radially toward the Earth and 32 azimuthal sectors are sampled each spin providing excellent coverage of the unit sphere. One spin takes approximately 10 seconds so high time resolution data is also available.

Since 1989 Los Alamos has flown a new generation of energetic particle detectors called Synchronous Orbit Particle Analyzers (SOPA) [*Belian et al.*, 1992]. The SOPA instruments are essentially a next-generation CPA and cover approximately the same energy range for electrons and ions and additionally provide some information on relativistic high-mass ions. The new generation of spacecraft also carry low-energy Magnetospheric Plasma Analyzers (MPA) [*Bame et al.*, 1993] which measure electrons and protons in the energy range 0-40 keV in 40 energy channels. Currently three new-generation and two old-generation spacecraft are operated simultaneously.

This data set, which spans 18 years and typically includes 3 simultaneous measurements distributed around the globe, represents a unique resource for space physics comparable to the NOAA GOES magnetometer measurements. Unlike GOES, however, this data set is only now being put on-line for easy access and collaboration. Currently, one-minute and 10-second averages are available by remote log-on and FTP (on Leadbelly.LANL.GOV—128.165.207.018) or using the World Wide Web interface (http://leadbelly.lanl.gov/lanl_ep_data/). Data are available for the time period from 1979 to the present.

3. ENERGETIC PARTICLES AND SUBSTORMS

The primary scientific use of the Los Alamos Geosynchronous Energetic Particle Database has been research into substorms and specifically the relationship between substorm injections and other substorm phenomenology. The injection of energetic particles at geosynchronous orbit is one of the most common and ubiquitous substorm signatures and occurs on average every 2.5 hours. However it is the rate and size of substorm injection that are indicators of the energy transfer processes in the magnetosphere.

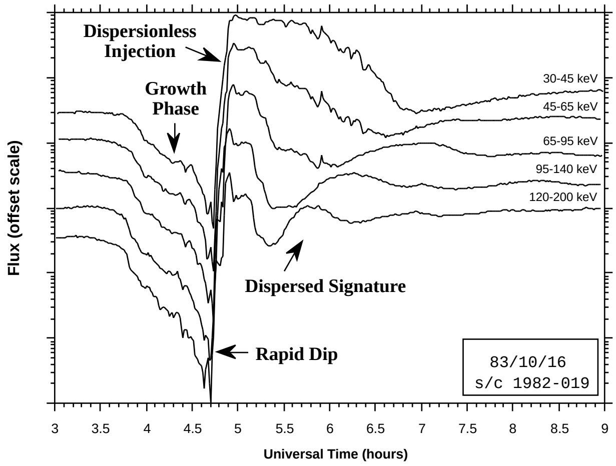

Figure 1. "Classic" substorm injection signature showing a growth phase dropout, a dispersionless injection and an energy-dispersed drift echo.

Figure 1 shows a "classic" substorm injection signature for a single, isolated substorm observed near local midnight. In the growth phase the plasma sheet thins and the enhancement of local drift shell splitting for different pitch angles results in a "cigar-like" pitch angle distribution [*Baker et al.*, 1978]. For a spacecraft located off the magnetic equator the thinning of the plasma sheet is equivalent to a motion of the spacecraft across drift shells and therefore across radial gradients so a gradual dropout of energetic particle fluxes is observed. This growth phase signature is only observed locally, in the region of plasma sheet thinning near midnight. At onset the plasma sheet thickens If this process were adiabatic the fluxes would return to their pre-existing levels. Instead an energization of the distribution is observed and the fluxes in the energetic portion of the distribution are enhanced one to two orders of magnitude. These newly injected particles remain on the geosynchronous drift shell where they gradient-curvature drift – electrons east and ions west – and can be observed as a dispersed injection signature at other local times around the globe. In Figure 1 an energy-dispersed injection signature can be observed following the first injection. This is actually a "drift echo" of the particles from the first injection after a full orbit around the Earth.

In the oral presentation I will provide a brief review of substorm injection mechanisms. While most substorm theories include an explanation for the cause of substorm injections none is entirely satisfactory. The standard model is the Convection Surge mechanism whereby the dipolarization of the field taps into a reservoir of heated particles in the tail. It was once thought that the heated particles were produced in a near-Earth reconnection region but the location of that acceleration region is now thought to be too far down tail. While some energy can be gained from the nonadiabatic dipolarization of the magnetic field, quantitative modeling has shown this to be inadequate to explain the observed heating of the distribution. *Delcourt et al.* [1990] invoked breaking of the first adiabatic invariant to explain the discrepancy. However, all non-adiabatic energization processes proposed contradict the little-known observation that electron injections are far more common than ion injections. Recently, other near-Earth instabilities such as the cross-tail streaming instability or the ballooning instability have been suggested. However, these theories do not quantitatively address the question of substorm injections.

Substorm "Flavors"

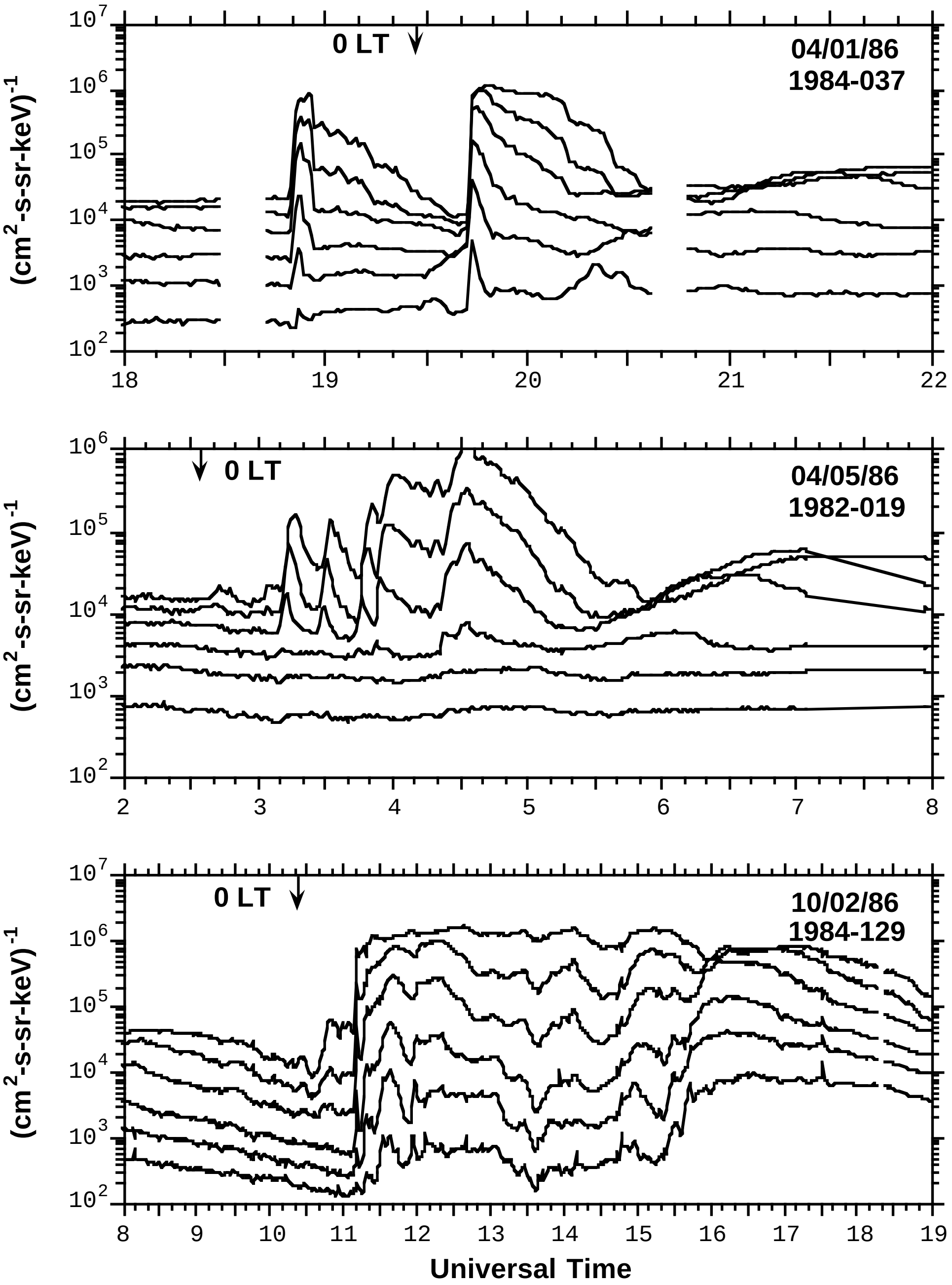

Figure 2. Three "flavors" of substorms. Three different days are shown. The time at which the satellite passed midnight is marked for each event. The top panel (4/1/86) shows two injections separated by about one hour. These could be two substorms or multiple activations in a single substorm. The second panel (4/5/86) shows multiple enhancements separated by only tens of minutes. Some of the earlier ones might indicate pseudobreakups but it is difficult to define which injection signifies "substorm onset". The bottom panel (10/2/86) shows a 5-hour period of almost continuous injection activity. Some injection signatures are dispersionless and some are dispersed. The first onset can be timed but subsequent onsets are very difficult to distinguish.

4. STORMS AND SUBSTORMS

With the ultimate physical cause of substorm injections in doubt it is not surprising that the relationship between substorms and storms vis-a-vis energetic particle injections is still more uncertain. Figure 2 shows that there is a clear hierarchy of injection signatures. The top plot shows two injections separated by about an hour in time. Depending on your definition these could be two independent substorms or two intensifications within a single substorm. The middle plot in Figure 2 shows a more clear example of a multiple onset substorm. Nothing is qualitatively different from a series of isolated injections but the proximity in time leads one to group these into a single event. The bottom plot in Figure 3 shows a further step in the hierarchy. This event shows nearly continuous injection activity for several hours (note the different time scales on the plots). The signatures get more dispersed as the spacecraft orbits away from local midnight..

Figure 3 shows an event on February 8, 1986. Each panel shows data from one of the three operating satellites. The left three plots show electrons (30-300 keV) and the right three plots show protons (≈70-≈600 keV). These signatures are both qualitatively and quantitatively different from the injection signatures in Figure 2. Here “injection” signatures are seen nearly simultaneously in both protons and electrons, simultaneously at all local times (all satellites). Several features are apparent. First we notice the regular saw-tooth pattern which is particularly apparent in the proton fluxes and in the electron fluxes prior to 1200 UT. The electron fluxes become much more variable after 1200 UT, particularly when the satellite is near midnight local time as indicated by the scale on the top of each plot. A final feature of note is the dropout of electron fluxes seen after 2230 UT at spacecraft 1984-129 (bottom plot). This is the signature of a magnetopause crossing near local noon and is indicative of extremely high solar wind dynamic pressure.

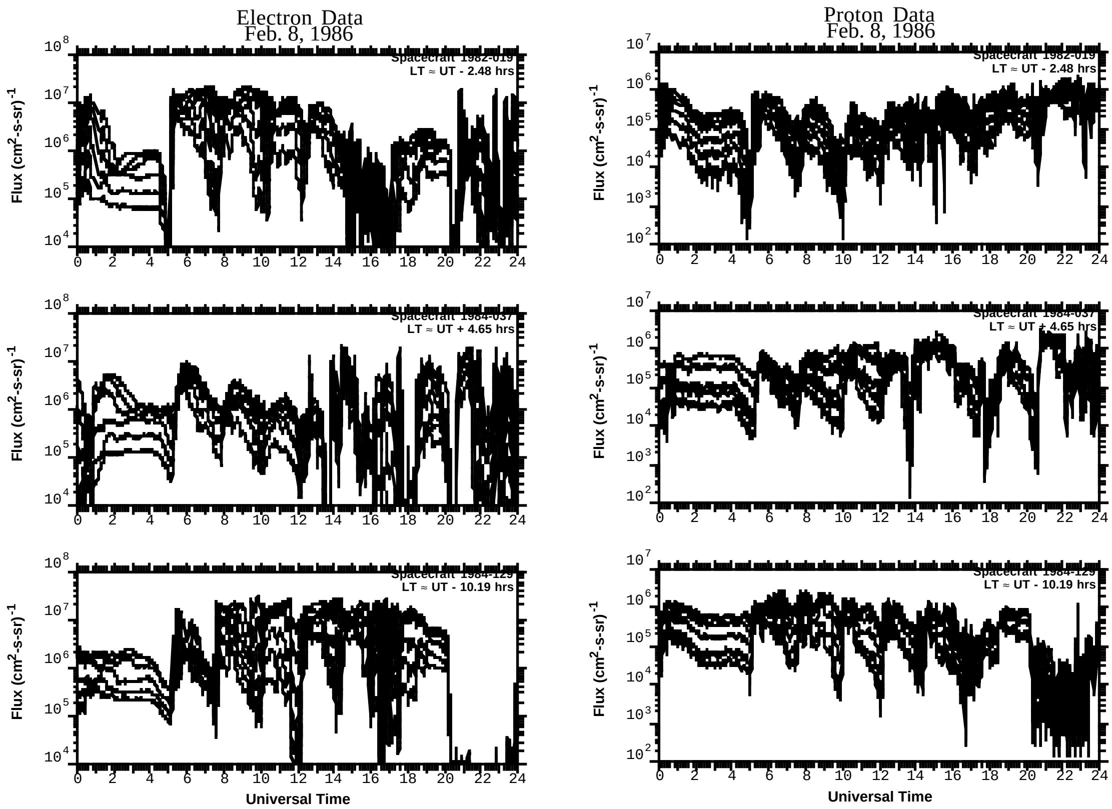

Figure 3. Electrons (left) and protons (right) for all three satellites on February 8, 1986.

It is apparent from Figure 3 that the magnetosphere is being driven quite strongly by the solar wind at this time which leads us to expect that storm conditions might prevail. This impression is confirmed in Figure 4 which shows DST for 1986 in 1-hour averages. The peak of DST occurred at the end of the day on February 8 and was -307 nT. The dates of the three plots in Figure 2 are also shown in Figure 4 and it is clear that the conditions were not at all unusual.

This preliminary analysis leads us to believe that the signatures of magnetic storms at geosynchronous orbit can be quite different from those during substorms – even multiple or continuously active intervals. It appears that under some conditions the energetic particle fluxes at geosynchronous orbit can enter into a coherent, global, saw-tooth-shaped oscillation. It is also observed (but not shown here) that as soon as DST begins to recover the active oscillatory behavior ends and normal substorm injection signatures are observed.

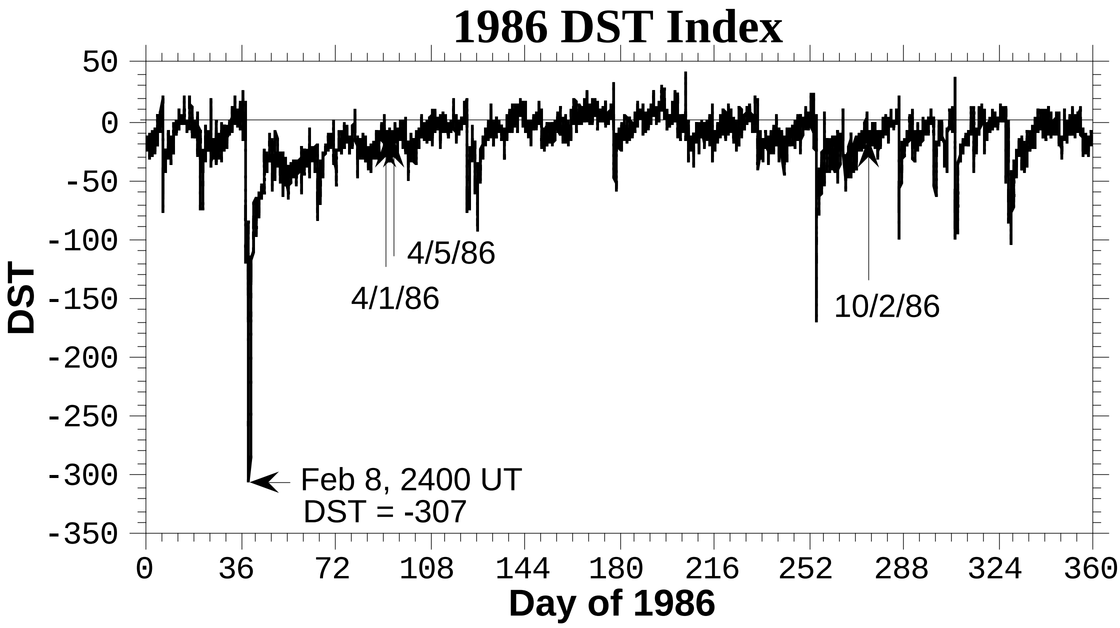

Figure 4. The DST Index for 1986 showing the times of the plots in Figures 2 and 3.

5. Conclusions...

This extended abstract is simply intended to whet one's appetite and many questions are left unanswered. Which signatures are characteristic of magnetic storm times? Are storms simply a collection of superimposed substorms which pump up the ring current? In that case, how does the rate of energetic particle injection relate to the strength of the ring current as measured by DST? These questions are the topics of current research and I will present preliminary findings at the Rikubetsu workshop.

6. REFERENCES

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